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(AASERT-93) Strained-Layer Multiple Quantum Well for High Linearity Modulation

5. FUNDING NUMBERS
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6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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F49620-94-1-0111

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

We have demonstrated high power, high RF efficiency (-17.8 dB) analog ssemiconductor waveguide modulator based upon Franz-Keldysh Effect (RKE) modulation at 1.3 um wavelength. The modulator has been operated with a multi-octave spurious free dynamic range (SFDR) of 106 dB-Hz, and a single octave SFDR of 124 dB-Hz. These results have been found to be independent of frequency, up to 4 GHz. We have studied and designed the waveguide modulator based upon a combination of FKE and Quantum confined Stark Effect (QCSE) for enhancing the link linear dynamic range. We have also demonstsrated a dual function analog receive/transmit operation for the semiconductor electroabsorption modulator. We have demonstrated, by adjusting the bias voltage to the waveguide device, it can operate as an effective high saturation photodetector as well as an effective modulator. We have also demonstrated the first high quality strained compensated multiple quantum well InGaP/InAsP materials at both 1.3 and 1.5 um wavelength. Up to one micrometer thick multiple quantum well region can be grown.

14. SUBJECT TERMS

15. NUMBER OF PAGES

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FINAL REPORT

AASERT Program Title: Strained-Layer Multiple Quantum Wells for High Linearity Modulation

AASERT Contract No.: F49620-94-0111

Report Period: December 31, 1993 - March 31, 1997

Principal Investigator: Professor Paul K. L. Yu; University of California, San Diego;
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Sponsoring Scientific Office: AFOSR/NE

Scientific Officer: Dr. Alan E. Craig, AFOSR/NE; Tel (202) 767-4984

(1) AASERT Evaluation Report

(a) **Parent DOD Contract No.:** F30602-91-C-0112
(Award duration: 8/91 - 2/95)

(b) **Total amount of funding in the parent contract:** $700,000
There are three equivalent graduate students annually supported by the parent contract prior to the AASERT award

(c) There are three equivalent graduate students annually supported by the parent contract after the AASERT award, before the end date of the parent contract.

(d) **Total amount of AASERT funding:** $89,355
There is presently a graduate student, Mr. Robert B. Welstand, supported by the AASERT award. Mr. Welstand is scheduled to finish his Ph.D. thesis before summer, 1997.

(e) **Certification of the student** (see next page)

(2) Final Technical Report

Technical Objective: In this project we concentrated on (1) the development the growth of high quality compressively strained InGaAsP/InGaAsP multiple quantum wells on InP substrates by organometallic vapor phase epitaxy (OMVPE) that are suitable for waveguide modulator and detector, (2) the optimization of the linearity performance of the external waveguide modulators based upon electroabsorption effects in semiconductor structures.

Technical Approach: The studies involve the study and design of semiconductor material structures grown by OMVPE. Grown layers are characterized by the X-ray diffractometry, the photoluminescence spectroscopy, and optical transmission spectroscopy. Device modeling is carried out in conjunction with the material properties. Waveguide modulators are fabricated and tested in a RF fiber optic link configuration.

Summary of Accomplishments in this program:

We have the following accomplishments in this program:

1. We have demonstrated high power, high RF efficiency (-17.8 dB) analog semiconductor waveguide modulator based upon Franz-Keldysh Effect (FKE) modulation at 1.3 μm wavelength. This is achieved with up to 43 mW optical power incident to the modulator. The modulator has been operated with a multi-octave spurious free dynamic range (SFDR) of 106 dB-Hz $^{2/3}$, and a single octave SFDR of 124 dB-Hz$^{4/5}$. These results have been found to be independent of frequency, up to 4 GHz. The highest frequency of operation of the modulator is beyond 30 GHz, while the packaged devices are tested up to 13.6 GHz. (Pub. #4-#7, #12)
2. We have studied and designed the waveguide modulator based upon a combination of FKE and Quantum confined Stark Effect (QCSE) for enhancing the link linear dynamic range. Preliminary model show that a multi-octave SFDR of 120 dB-Hz$^{2/3}$ is possible for an optimized structure combining both effects.(Pub. #9,#10)
3. We have also demonstrated a dual function analog receive/transmit operation for the semiconductor electroabsorption modulator. We have demonstrated, by adjusting the bias voltage to the waveguide device, it can operate as an effective high saturation photodetector as well as an effective modulator. The waveguide photodetector can be operated with more than 20 mA of photocurrents and generated low harmonic signals. (Pub. #11)

4. We have also demonstrated the first high quality strained compensated multiple quantum well InGaP/InAsP materials at both 1.3 and 1.5 μm wavelength. Up to one micrometer thick multiple quantum well region can be grown without degradation in the optical properties of the materials. These materials will be further studied for high power waveguide modulator designs. (Pub. #1-#3, #8)

Publications:

1. "Strained-layer InAsP/InGaP MQWs grown by MOVPE", by P. K. L. Yu, M. Markarian, R. Welstand, X. S. Jiang, A. R. Clawson, and S. S. Lau, SPIE Proceeding, Vol. 2149, pp. 44, 1994.
2. "Strained InAsP/InGaP Superlattice Grown by MOVPE", by X. S. Jiang, R. Welstand, M. Markarian, A. R. Clawson, S. S Lau, and P. K. L. Yu, presented at the 36th Electronic Materials Conference, June 1994, Boulder Colorado.
3. "Strain compensated InAsP/InP/InGaP multiple quantum well for 1.5 μm wavelength", by X. S. Jiang, and P. K. L. Yu, Appl. Physics Lett., 65, pp. 2536, 1994.
4. "High Spurious Free Dynamic Range Fiber Link Using ASemiconductor Electroabsorption Modulator", by C. K. Sun, S. A. Pappert, R. B. Welstand, J. T. Zhu, P. K. L. Yu, Y. Z. Liu, and J. M. Chen, IEE Electronics Letters, 31, pp. 902-903, 1995
5. "Enhanced Linear Dynamic Range Property of Franz-Keldysh Effect Waveguide Modulator", R. B. Welstand, C. K. Sun, S. A. Pappert, Y. Z. Liu, J. M. Chen, J. T. Zhu, A. L. Kellner, and P. K. L. Yu, IEEE Photonics Technology Lett., 7, pp. 751-754 (1995).
6. "High Dynamic Range Fiber Optic Links Using Semiconductor Electroabsorption Modulators", by S. A. Pappert, C. K. Sun, R. B. Welstand, P. K. L. Yu, Y. Z. Liu, and J. M. Chen, presented at IEEE LEO Summer Meeting on RF Optoelectronics, Aug. 9, 1995, Keystone, Colorado.
7. "High Dynamic Range in Electroabsorption modulator for Analog links", by R. B. Welstand, C. K. Sun, Y. Z. Liu, S. A. Pappert, J. T. Zhu, J. M. Chen, and P. K. L. Yu, SPIE Proceeding, Vol 2560, pp. 44-49 (1995).

8. "High Quality $In_{1-x}(Ga_x)As_yP_{1-y}$/InP compressive Strain Quantum Well Structures Grown by LP-MOCVD," J.T. Zhu, A.R. Clawson, and P.K.L. Yu, Proc. of Mat. Res. Soc., pp. 45-50 (1996).

9. "High Dynamic Range Fiber-optic Links using III-V Electroabsorption Modulators," R.B. Welstand, C.K. Sun, S.A. Pappert, Y.Z. Liu, Q.Z. Liu, S.S. Lau and P.K.L. Yu, Proceeding of PSAA-6, the sixth annual ARPA Symposium on Photonic Systems for Antenna Applications, Mar 5-7, 1996, Monterey, CA.

10. "High Dynamic Range Semiconductor Electroabsorption Modulator Structures," R.B. Welstand, C.K. Sun, S.A. Pappert, Y.Z. Liu, P.K.L. Yu, Proceeding of The 5th Biennial Department of Defense Photonics Conference, p. 209-212, March 26-28, 1996. McLean, Virginia

11. "Dual-Function Electroabsorption Waveguide Modulator/Detector for Optoelectronic Transceiver Applications," R.B. Welstand, S.A. Pappert, C.K. Sun, J.T. Zhu, Y.Z. Liu, P.K.L. Yu, IEEE Photonics Technical Letters , 8, p. 1540-1542, (1996).

12. "Phase Noise and Dynamic Range of Analog Fiber Links using Electroabsorption Modulators", R.B. Welstand, R. J. Orazi, C.K. Sun, H. G. Rao, Y.Z. Liu, S.A. Pappert, and P.K.L. Yu, Proceeding the SPIE Symposium, Vol. 2844, pp. 27-33 (1996).

(3) Financial Report

(To be provided by OGSR)

(4) Invention Report

(to be provided by OGSR: there has been no invention in this project)

GRANT NUMBER: F49620-94-1-0111

FORM A2-2

NATION AWARDS FOR SCIENCE & ENGINEERING RESEARCH TRAINING (AASERT) REPORTING FORM

The Department of Defense (DOD) requires certain information to evaluate the effectiveness of the AASERT program. By accepting this Grant Modification, which bestows the AASERT funds, the Grantee agrees to provide the information requested below to the Government's technical point of contact by each annual anniversary of the AASERT award date.

1. Grantee identification data: (R & T and Grant numbers found on Page 1 of Grant)

a. University of California, San Diego
University Name

b. AFSOR F49620-94-1-0111
Grant Number

c. _____
R & T Number

d. Paul Yu
P.I. Name

e. From: 12/31/93-To: 3/31/97
AASERT Reporting Period

... to which AASERT award is attached is referred to hereafter as "Parent Agreement."

2. Total funding of the Parent Agreement and the number of full-time equivalent graduate students (FTEGS) supported by the Parent Agreement during the 12-month period prior to the AASERT award date.

a. Funding: $700,000

b. Number FTEGS: 3

3. Total funding of the Parent Agreement and the number of FTEGS supported by the Parent Agreement during the current 12-month reporting period.

a. Funding: $700,000

b. Number FTEGS: 3

4. Total AASERT funding and the number of FTEGS and undergraduate students (UGS) supported by AASERT funds during the current 12-month reporting period.

a. Funding: $ 89,355

b. Number FTEGS: 1

c. Number UGS: 0

VERIFICATION STATEMENT: I hereby verify that all students supported by the AASERT award are U.S. citizens.

Principal Investigator

4/2/97
Date